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MTMC REPORT TE 78-44

MANUAL PROCEDURES FOR ESTIMATING MARINE TERMINAL THROUGHPUT

PART TWO OF TWO

CONDENSED PROCEDURES

MARCH 1978

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MILITARY TRAFFIC MANAGEMENT COMMAND
TRANSPORTATION ENGINEERING AGENCY
NEWPORT NEWS, VIRGINIA 23606

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I. INTRODUCTION

A methodology for estimating the cargo throughput capability of marine terminals was developed by the Military Traffic Management Command Transportation Engineering Agency. The methodology systematizes input factors and organizes them into mathematical expressions with which one can calculate cargo throughput rate. Marine terminal capability can be estimated for four types of ships: break-bulk, container, roll-on/roll-off, and LASH/SEABEE. The procedure used to estimate capability is the weak-link analysis, and is applicable for both loading and unloading ships.

The purpose of this part is to provide a procedure, condensed from Part One of this report[1/], for estimating marine terminal capability. This part summarizes the derivations and analyses of Part One and gives step-by-step procedures for estimating port capability. A worksheet format is provided to aid in the collection of all data necessary to make the calculations. As these reference sheets are intended as an overall guide, the user may find it helpful to develop his own expanded worksheets to organize collected data and repetitive calculations. This part is intended as a time-saving reference guide, for use after reading the first part, to assist in gaining a full understanding of how to apply the procedures.

1/ "Review, Derivations, and Procedures," Manual Procedures for Estimating Marine Terminal Throughput, Part One, MTMC Report TE 73-44.

II. STEP-BY-STEP PROCEDURE

A. Procedure for estimating port throughput for single berths. The process described below determines the throughput capacity of a port with one berth, a so-called "berth" system. Perform the steps in sequence, except where otherwise indicated. Details for performing each calculation are given in Section III.

STEP 1 - Using the Movements A through E Reference Sheet, Table I (Section III), find the capacities of subsystems A through E. For example, consider cargo movement A, which denotes cargo movement from outside the gate to inside the gate, as shown in Figure 1. The reference sheets are oriented to be filled out by user, from left-to-right. The extreme right-hand column is the cargo throughput capacity for a particular movement in MTON per month, which is the desired ultimate quantity. Either the variables on the reference sheet are self-explanatory, or notations are given on the sheet to aid in the calculation. First, it is seen that there are two possible modes for movement A - rail and truck. The next two columns, N and H, do not pertain to movement A since a two-way trip is not involved. Column n, the number of vehicles per day moved past the gate, is given by N_3 times N_2 for rail, and S divided by t_A for truck. N_3 is the number of trains per day that can be received at the gate, and N_2 is the number of railcars per train. S is the number of shift hours worked per day for movement A, and t_A is the amount of time for one truck to complete movement A, in hours per truck. Now, knowing the number of vehicles per day, simply multiply by the capacity in MTON, M, of the average vehicle to obtain the movement capacity.

For rail,

$$\frac{\text{MTON}}{\text{month}} = \left(30 \ \text{MnWGL}\right)$$

where n is the number of railcars per day, and W, G, and L are defined on the worksheet as factors which degrade movement capacity.

For truck,

$$\frac{\text{MTON}}{\text{month}} = \left(30 \ \text{MnWGL}\right)$$

where n is the number of trucks per day.

For both truck and rail, the movement capacity is summed in the last column to give the total capacity for movement A.

The same approach is followed for the rest of the movements.

STEP 2 - Using the Movement F Reference Sheet, Table II (Section III), determine the maximum berth throughput capacity, F_{max}, for the appropriate type of berth.

STEP 3 - Examine the calculated throughput rates for each movement, A through F. The lowest rate identifies the weak link. If this weak link is any one of the movements A through E, go to STEP 8. If F is the weak link, go to STEP 4.

STEP 4 - Calculate the requirement of the holding area capacity $\widehat{Q}$, by the procedure of paragraph D, Section III, using the minimum ship cycle time, $T_{c, min}$, from the Movement F Reference Sheet worked out at STEP 2.

STEP 5 - Compare the required holding area, $\widehat{Q}$, with the available holding area. If the available area is adequate, the port throughput capacity is equal to F_{max}, the maximum berth throughput capacity. For this case, this is the last step. However, if the available area is not adequate, go to STEP 6.

STEP 6 - By trial and error, increase T_c (which increases t_3, and decreases $\widehat{Q}$) in the computation of $\widehat{Q}$ until the value of $\widehat{Q}$ is equal to the available holding area. Plotting a simple graph of $\widehat{Q}$ vs T_c will aid the solution. From paragraph D 4, Section III, the equations for $\widehat{Q}$ show a straight line variation with T_c for Cases III and IV. For Case V, $\widehat{Q}$ is inversely proportional to T_c. As T_c is increased, the value of $\widehat{Q}$ will approach the value of C. Make sure that the value of $\widehat{Q}$ does not go below the value of C, since the equation is not valid for that case. Also make sure that the restrictions on the equations are not violated as T_c is increased. For example, as T_c increases, Case V on the decision chart becomes Case III, then Case I, at which point $\widehat{Q} = C$. Case IV becomes Case II as T_c increases, at which point $\widehat{Q} = C$.

STEP 7 - Since T_c is now greater than it was when calculated by using the maximum berth throughput, F_{max}, the new values of N and F must be calculated from paragraph C 5, Section III. This is the last step for this case.

STEP 8 - One of the movements A through E was the weak link. Write K for the throughput capacity of the weak link. At this step, calculate the ship cycle time which makes the berth throughput rate equal to K by the equation from paragraph C 5, Section III.

$$T_c = \frac{720\ C}{K}$$

The new number of ships per month, N, is given by

$$N = \frac{K}{C}$$

STEP 9 - Using the value of T_c from STEP 8, calculate the holding area requirement, $\widehat{Q}$, for the berth by the method given in paragraph D, Section III. If the available holding area is greater than or equal to $\widehat{Q}$, the weak link throughput, K, is the berth throughput capacity. For this case, this is the last step. If the area is not adequate, go to STEP 10.

STEP 10 - By trial and error, increase T_c in the computation of $\widehat{Q}$ until the value of $\widehat{Q}$ is equal to the available holding area. Note that this step is identical to STEP 6, except for the numerical values. Refer to STEP 6 for aid in this calculation.

STEP 11 - Since T_c is now greater than it was when calculated by using K, the throughput capacity of the weak link, the new values of N and K must be calculated. Using the new value of T_c, the new N is given by

$$N = \frac{720}{T_c}$$

and the new K is given by

$$K = NC$$

B. PROCEDURE FOR ESTIMATING PORT THROUGHPUT FOR MULTIPLE BERTHS

1. If the port is organized into independent berth systems (that is, the port can be regarded as a collection of separate ports, each with one berth), simply follow the steps of paragraph A, above, for each berth system to find its capacity, and them sum the results for the final port figure.

2. Usually, however, multiple berths will be served by common holding areas and other facilities. In this case, calculating the total throughput capacity exactly is a very complex and tedious affair at best. The procedure described below is a heuristic method which should yield a reasonable answer (that is, the capacity determined is achievable, and probably nearly optimal) without undue labor.

STEP 1 - Using the Movements A through E Reference Sheet, Table I, find the capacities of subsystems A through E.

STEP 2 - Using the Movement F Reference Sheet, Table II, calculate the berth throughput capacity for each berth in the port. Suppose that there are n berths; let the capacity of berth i be written F_i for $i = 1, 2, \ldots, n$.

STEP 3 - Using the procedure of paragraph D, Section III, calculate the required peak holding capacity $\widehat{Q}_i$ for each berth, $i+1, \ldots, n$.

STEP 4 - Estimate the total peak holding area $\widehat{Q}$ required by summing the $\widehat{Q}_i$:

$$\widehat{Q} = \widehat{Q}_1 + \widehat{Q}_2 + \ldots + \widehat{Q}_n$$

STEP 5 - Compare $\widehat{Q}$ with the available holding area - suppose this is Z MTON. If $\widehat{Q} \leqslant Z$, the required capacity is the minimum of the tonnages for movements A through F. For this case, this is the last step. If $\widehat{Q} > Z$, go to STEP 6.

STEP 6 - If $\widehat{Q} > Z$, apportion the available capacity among the berths. For berth i, consider the available capacity Z_i for the berth to be

$$Z_i = Z \frac{\widehat{Q}_i}{\widehat{Q}}$$

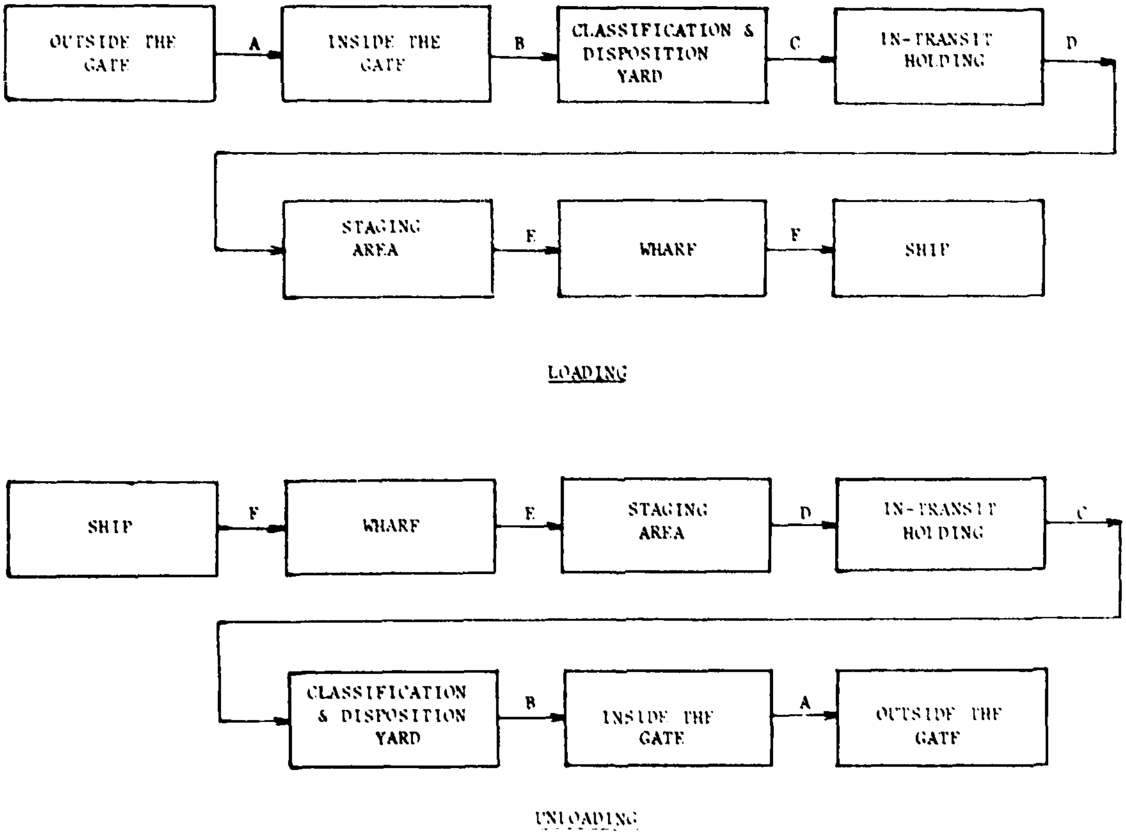
STEP 7 - For each berth, perform STEPS 6 and 7 of paragraph A, above, to find the new throughput tonnage permitted by the space available for in-transit storage.

STEP 8 - Sum the new berth throughput tonnage capacities to find the new total berth throughout capacity for Movement F. Again, the minimum of the tonnages for movements A through F is the final port capacity.

III. SUBSYSTEM CALCULATIONS FOR CARGO THROUGHPUT

A. GENERAL CONCEPT

The format for the weak-link analysis of transportation movements in a marine terminal is shown in Figure 1. The terminal system as a whole **is** broken down into subsystems and each one is analyzed separately. The cargo throughput rate is calculated for each movement A through F, as shown in Figure 1. The movement with the minimum rate is the weak link. Then, the holding area requirement is determined for the output of the weak link. If the available holding area is inadequate, the cargo throughput rate for the weak link is adjusted downward until the required holding area is approximately equal to the available holding area. The cargo throughput rate of the weak link is, then, the actual cargo throughput rate of the terminal.



NOTE: In a given operation, some subsystems may not be required or used, and they are omitted.

Figure 1. Format for Weak-Link Analysis.

B. SUBSYSTEMS A THROUGH E

1. Each separate derivation for the cargo movement of subsystems A through E is shown in Part One of this report.[2] There are three main equations to calculate movement of cargo between two points. The trip may be one-way or two-way, depending on the type of vehicle.

Consider first a two-way trip to calculate the cargo throughput (MTON per day) moved by a vehicle for one of the movements, using the equation (1)

$$\frac{\text{MTON}}{\text{day}} = nMWGL \tag{1}$$

where

n = number of vehicular loads that can be moved in a given movement per day.

Also, n is given by the equation $n = \frac{NS}{H}$

M = number of MTON per vehicular load

W = weather factor

G = night productivity factor

L = shift change factor

N = number of vehicles available for a given movement

S = number of shift hours worked per day

H = time in hours for round trip of a vehicle for a movement, including pickup and dropoff time

Now,

$$H = \frac{2d}{5280V} + H_1 + H_2 \tag{2}$$

where

d = one-way distance, in feet, that vehicle is to travel for a movement

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[2] MTMC Report TE 73-44, Part One, op. cit.

V = average velocity of the vehicle, in miles per hour, for a movement

H_1 = pickup time, average time, in hours, for the vehicle to pickup the load at the beginning of the movement

H_2 = dropoff time, average time, in hours, for the vehicle to dropoff the load at the end of the movement

For a one-way trip, the equation for the movement capacity, equation (1), is the same as for the two-way trip, but the equation for the vehicular rate, n, is different.

<u>For rail</u>

$$n = N_2 N_3$$

where

N_2 = number of railcars per train

N_3 = number of trains per day that can be received at the gate

<u>For truck</u>

$$n = S/_{t_A}$$

where

t_A = number of hours per truck, amount of time for one truck to complete a given movement

Except for Movement A, which is simpler than the rest, all of Movements B through E can be calculated by the same basic process. (See Movements A through E Reference Sheet, Table I.) This sheet includes all definitions of quantities to be computed or supplied by the user, and is presented in such a way that an actual worksheet for computation could be copied from it. Note that each column heading, for data to be used in a later computation, carries a letter code. In the formulae of the reference sheet, the user will substitute for a column-heading letter the number appearing in the same row as the formula in the referenced column.

TABLE I
MOVEMENT A THROUGH E REFERENCE SHEET

Movement	Vehicle	Number of Vehicles (N)	Time in Hours for one Vehicle to Complete Movement (H)	Vehicular Rate in No. of Veh per Day (n)	Movement Capacity for each Type of Vehicle (MTON per month)	Movement Capacity sum of all Vehicles (MTON per month)
A	Rail	NA	NA	N_3N_2 (Recd per Day Supply Figures)	30 MnWGL	Sum
	Truck	NA	NA	S/t_A	30 MnWGL	
B	Rail	N_1N_2	Equation (2)*	NS/H	30 MnWGL	Sum
	Truck		Do	Do	30 MnWGL	
C	Rail	N_1N_2	Do	Do	30 MnWGL	
	Truck		Do	Do	30 MnWCL	Sum
	Straddle Carrier		Do	Do	30 MnWGL	
D	Rail	N_1N_2	Do	Do	30 MnWGL	Sum
	Truck		Do	Do	30 MnWGL	
	Straddle Carrier		Do	Do	30 MnWGL	
E	Rail	N_1N_2	Do	Do	30 MnWGL	
	Truck		Do	Do	30 MnWGL	
	Straddle Carrier		Do	Do	30 MnWGL	Sum
	Forklift		Do	Do	30 MnWGL	

*Equation (2):

$H = \frac{2d}{5280\ V} + H_1 + H_2$ (the value to enter in column H of the worksheet

Notations:

- N_1 - number of locomotives available for a particular movement
- N_2 - number of railcars per train
- N_3 - number of trains per day that can be received at gate
- M - capacity of vehicle (railcar, truck, straddle carrier, and so forth, as appropriate) in MTON
- W - weather factor (para B2)
- G - night productivity factor (para B3)
- L - shift change factor (para B4)
- S - number of shift hours per day
- t_A - number of hours per truck, amount of time for one truck to complete a given movement
- d - one-way distance vehicle is to travel (average)
- V - average vehicle velocity, miles/hr
- H_1 - pickup time in hours
- H_2- drop-off time in hours

2. The weather factor, W, noted on the reference sheet, degrades the throughput capability to account for the effects of adverse weather. Thus, if W_1 is the fraction of total time loss due to severe or inclement weather, $W = 1 - W_1$. (Note that $W_1 < 1$, necessarily, and that W may be different in other types of operations. For example, rain may not affect container loading but would affect break-bulk loading.)

3. The night productivity factor accounts for the time loss due to reduced visibility. If P_1 shift hours are worked in daylight and P_2 shift hours are worked at night

then,

$$G = \frac{P_1 + 0.75\, P_2}{P_1 + P_2}$$

for a 25-percent nighttime degradation rate.

4. The shift-change factor, L, accounts for time loss due to changing work shifts, including lunch breaks. L_1 is defined as the fraction of total time loss due to shift changes, including lunch breaks. This factor must be considered for every different operation. L_1 is easily calculated for all operations except those at the berth, since at the berth, there is no time loss due to shift change between ships--only during shiploading time. For this case, L_2 is defined as the number of hours per shift. L_3 is defined as the number of hours lost per shift, including lunch breaks. Therefore, the number of shifts required to load the ship is

$$t_L \div \left(L_2 - L_3\right)$$

and

$$L_3\left[\frac{t_L}{L_2 - L_3}\right]$$

gives the fraction of total hours lost while loading one ship, which is L_1;

therefore,

$$L = 1 - L_1 = 1 - \frac{L_3}{L_2 - L_3}$$

C. SUBSYSTEM F

The derivation for the cargo movement of subsystem F is shown in the main report for four types of ships: general cargo (break-bulk), container, LASH/SEABEE, and roll-on/roll-off. The Movement F Reference Sheet, Table II, is laid out in the same general way as Table I. Here, however, not all factors are displayed, only major factors in the calculations. The reference sheet cites the paragraph that shows how to evaluate the reference sheet entry.

1. Time to load or unload break-bulk ship

Determine the following data for the type break-bulk ship being loaded or unloaded:

where

S_i = loading or unloading rate in MTON per hour for one gang operating at hatch i, where i=1, 2, . . . , n and there are n hatches for the ship

H_i = capacity of hatch i in MTON

D_i = capacity of deck load at hatch i, in MTON

P_i = loading or unloading and securing rate for deck cargo in MTON per hr, one gang, at hatch i

$(1 + f)$ = effective number of gangs per hatch, where f is the efficiency of a second gang when two gangs work one hatch, so that $f < 1$, $f = 0$ for one gang, $f = 0.8$ for two gangs

Then calculate the loading and unloading time for each hatch. We denote this by t_i for hatch i. The formula is:

$$t_i = \frac{1}{1 + f}\left[\frac{H_i}{S_i} + \frac{D_i}{P_i}\right]$$

TABL
MOVEMENT F RE

Type of Berth	Time to load/ unload ship, in hours t_L	Time to process papers and berth ship, in hours t_1	Time to prep ship for sail, in hours t_2	Dead Time,		
				Ship cycle time, in hours $T_{c, min}$	Number of ships per month N_{max}	Be in or mo mo per
Break bulk	para C1	determine number1/	determine number1/	para C6	para C6	
Container	para C2	do	do	do	do	
LASH/SEABEE	para C3	do	do	do	do	
RORO	para C4	do	do	do	do	

1/Number supplied by port operator as determined by local conditions.
2/s, dredging factor. See paragraph C8.
3/C, ship capacity in MTON, or number of containers, or number of barges, or number of vehicl

ABLE II
REFERENCE SHEET

me, $t_3 = 0$	Dead Time, $t_3 > 0$			Dredging factor, s[2]	Ship Capacity C[3]
Berth throughput rate, in MTON per month, or containers per month, or barges per month, or vehicles per month F_{max}	Ship cycle time, in hours T_c	Number of ships per month N	Berth throughput rate, in MTON per month, or containers per month, or barges per month, or vehicles per month F		
para C6	para C5	para C5	para C5	para C8	para C7
do	do	do	do	do	do
do	do	do	do	do	do
do	do	do	do	do	do

ehicles. See paragraph C7.

2

Then, if the hatches are worked simultaneously, the time to load or unload the ship is

$$t_L = \frac{1}{WGL} \left[\max_{i = 1, \ldots, n} t_i \right]$$

If the hatches are worked sequentially, the time to load or unload the ship is:

$$t_L = \frac{1}{WGL} \left[t_1 + t_2 + \ldots + t_n \right]$$

with the weather factor W, the night factor G, and the shift-change factor L defined as they were in paragraphs B 2, B 3, and B 4, respectively.

2. Time to load or unload a containership

Determine the following data for the type of containership to be loaded or unloaded:

C = capacity of ship in number of containers

n = number of container cranes working the vessel

A = container crane rate for one crane, number of containers per hour then compute:

$$t_L = \frac{C}{n\ A\ W\ G\ L}$$

with the weather factor, W, the night factor, G, and the shift-change factor, L, appropriate to this operation.

3. Time to load or unload a LASH or SEABEE with barges

Determine the following data for the type of barge ship to be loaded:

C = capacity of the ship in number of barges

A = rate for ship elevator, including barge maneuvering time, number of barges per hour

then,

$$t_L = \frac{C}{A\,W\,G\,L}$$

with the weather factor, W, the night factor, G, and the shift-change factor, L, appropriate to this operation.

4. Time to load or unload a roll-on/roll-off vessel

Determine the following data for the type of RORO ship to be loaded or unloaded:

C = capacity of the ship in number of vehicles

n = number of ramps to be used

R = ramp loading or unloading rate per ramp, in number of vehicles per hour

then,

$$t_L = \frac{C}{n\,R\,W\,G\,L}$$

with the weather factor, W, the night factor, G, and the shift-change factor, L, appropriate to this operation.

5. Ship cycle time ($t_3 > 0$)

The ship cycle time, T_c, is defined as the time, in hours, required for one complete cycle of operations which includes berthing, unloading or loading, sailing, and dead time. That is,

$$T_c = t_L + t_1 + t_2 + t_3$$

t_3 = the time, in hours, after a ship has sailed and before another ship starts to berth (dead time)

t_2 = the time, in hours, between completion of loading or unloading and actual sailing

t_1 = the time, in hours, to berth the ship and begin loading or unloading

However, this equation is not normally used to calculate T_c. If the weak link is not at the berth, then the berth output cannot be F_{max}, $T_c \neq T_{c,\,min}$, and T_c is determined by the constraint on either the holding area or one of the cargo movements A through E. If the available holding area is a constraint, and a new ship cycle time has been calculated from STEP 6, then N is given by

$$N = \frac{720}{T_c}$$

and

$$F = NC$$

If the constraint is at one of the cargo movements A through E, the cargo throughput is lesser in value than F_{max} and is defined as K.

Therefore, N is given by

$$N = \frac{K}{C}$$

and T_c is given by

$$T_c = \frac{720}{N} = \frac{720\ C}{K}$$

6. <u>Ship cycle time ($t_3 = 0$)</u>

The minimum ship cycle time, $T_{c,\,min}$, occurs when

$$t_3 = 0$$

therefore,

$$T_{c,\,min} = t_L + t_1 + t_2$$

when T_c is a minimum value, both N and F are maximum values giving

$$N_{max} = \frac{720}{T_{c,\,min}}$$

and

$$F_{max} = N_{max} C$$

7. Ship capacities

a. Break bulk. With the notation of paragraph 1 above

$$C = H_1 + H_2 + \ldots + H_n + D_1 + \ldots + D_n$$

b. Containership. Find C by multiplying the number of containers carried by the average MTON payload of a container, if units of C are desired in MTON.

c. LASH/SEABEE. Find C by multiplying the number of barges by the MTON payload of a barge if units of C are desired in MTON.

d. RORO. Find C by multiplying the (average) number of vehicles carried by the average MTON displacement of a vehicle, if units of C are desired in MTON.

e. Compare C with available holding area. Compare the capacity of the ship, C, with the portion of the available holding area reserved for that type of ship. If the capacity of the area is less than the value of C, then the ship cannot be fully loaded, but can be partially loaded. Redefine C to be equal to the value of the available holding area. For example, a containership has a capacity of 800 containers, C = 800 containers, and the portion of the available holding space allotted to container operations has a capacity of only 700 containers. The ship cannot be fully loaded, but must be partially loaded with 700 containers. Therefore, the ship capacity must be redefined as C = 700 containers.

8. Dredging factor.

The dredging factor is to be used only if a yearly estimate of berth throughput is needed. The dredging factor cannot be applied realistically to a monthly figure, because dredging is not done every month, and applying the factor would change the number of ships per month and the ship cycle time. In actuality, the berth would operate month after month unaffected by dredging, and then cease operations completely while dredging was done. The fraction of the total time lost is defined as s_1. Therefore,

$$s = 1 - s_1$$

and the annual berth output is 12 s times the monthly berth output.

D. IN-TRANSIT HOLDING AREA REQUIREMENT

The derivation of the formulae used in this paragraph is given in Part One of this report. Section II, Paragraph A, STEPS 6 and 7 above show how to use these formulae in estimating the port throughout capacity.

1. First, determine the cargo input period, the time interval over which a shipload of cargo is fed into in-transit storage. If the cargo is assumed to arrive not earlier than X days before ship arrival and not later than Y days before ship arrival, we have

   t_a = cargo input period = $24(X - Y + 1)$ in hours

2. Next, find the cargo holding time, t_h

   Determine:

   t_1 = berthing time for the vessel, in hours (between arrival and time ready to load). This should be taken from the Movement F Reference Sheet (Table II)

   then, calculate

   $$t_h = 24(Y - 1) + t_1$$

3. With all these factors available, the following important quantities can be computed:

   $\overline{Q}$ = the mean holding area requirement per berth

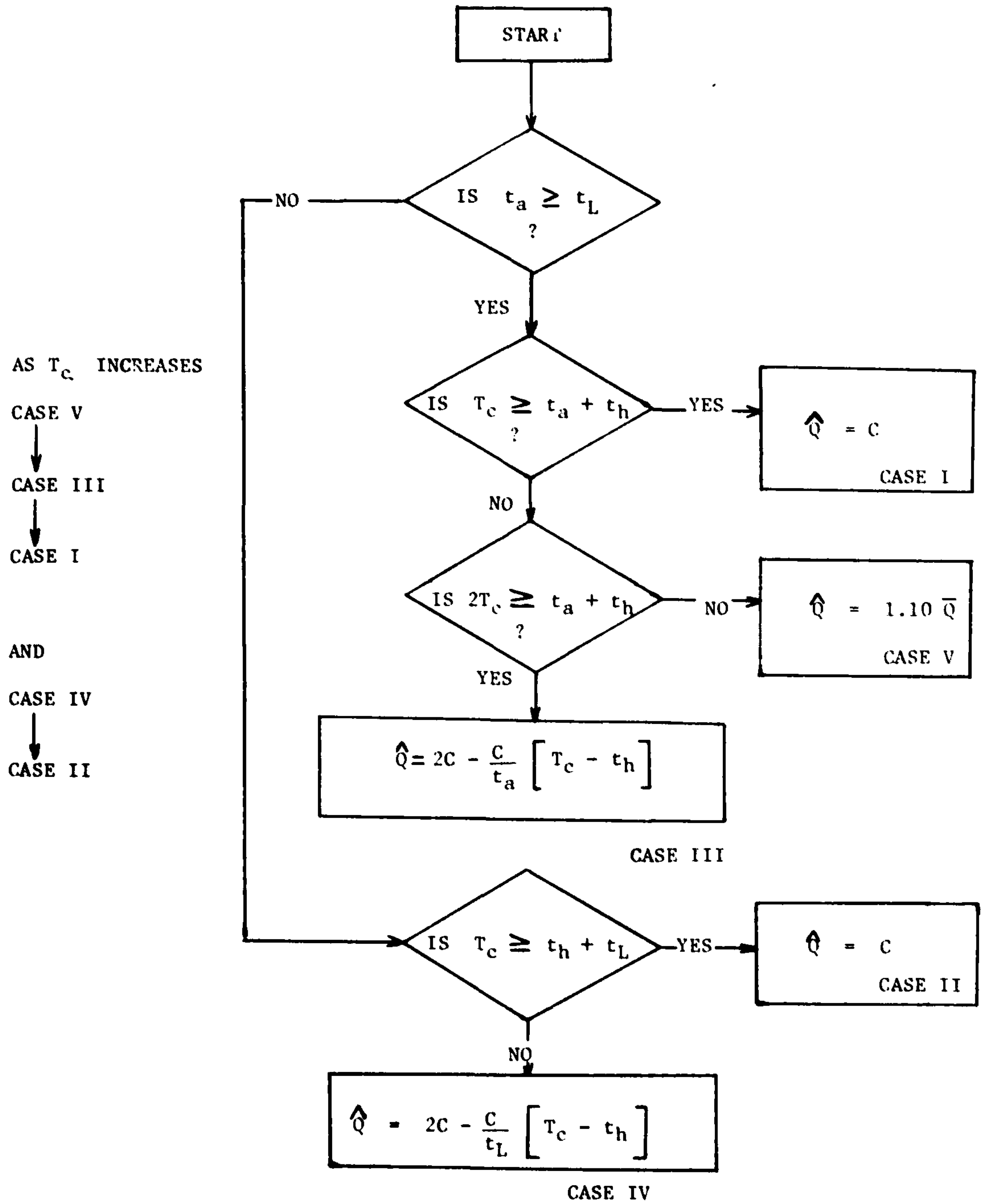
   and

   $\widehat{Q}$ = the maximum or peak holding area requirement per berth

   Recall, C is the capacity of the type of vessel being loaded. C may be measured in MTON, containers, vehicles, or barges, depending on the ship type, and $\overline{Q}$ and $\widehat{Q}$ will then be in the same units. Calculate $\overline{Q}$ as follows:

$$\overline{Q} = C \left[\frac{2t_h + t_a + t_L}{2T_c} \right]$$

4. To compute $\widehat{Q}$, follow the decision chart given below:



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Port Capacity; Cargo Throughput; Throughput Analysis; Port Methodology; Port Capability; Marine Terminals; Terminal Studies.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A methodology was developed for determining and predicting the cargo throughput capability of marine terminals. It systematizes the input factors into mathematical expressions with which one can manually calculate cargo throughput rates. The methodology enabled planners and engineers to estimate marine terminal capability (port capacity) for four types of cargo: break-bulk, containerized, roll-on/roll-off, and LASH/SEABEE barges. The procedure used

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for estimating capability is the weak-link analysis, in which each basic subsystem in a port is analyzed separately to determine its cargo throughput capability. The subsystem having the least capability is the weak link, and the output of the port system as a whole can be no greater than that of this weak link. Example problems are shown, with detailed calculations, for marine terminal operations with the four different types of cargo mentioned above. Also, an example is shown wherein analysis is made of combined operations. The developed procedure is applicable either for loading ships in CONUS or for unloading ships at overseas ports.